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RECENT RESULTS OF CREEP TESTS ON HEAT-RESISTANT STEEL X22CrMoV 12.1

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16. Abstract

Evaluation of the results of creep test programs carried out in factory laboratories in the GDR on the heat-resistant steel X22CrMoV 12.1. Elongation and creep strength values are presented, as well as values for creep rupture strength and temper hardening. These results are compared with previously published GDR values and with the results obtained by laboratories in other countries.

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RECENT RESULTS OF CREEP TESTS ON HEAT-RESISTANT STEEL X22CrMoV 12.1

Gerhard Belka, Guenther Muench and B. Melzer

1. Introduction

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The heat-resistant steel X22CrMoV is widely used in the construction of turbine blades, disks and shafts, screws, nuts and other heat-resistant structural components. Numerous studies in the literature [1-14] have reported on the creep and precipitation behavior of this steel. The testing programs of several countries have achieved remarkable testing times for X22CrMoV 12.1 steel which have provided mean and minimum values for 100,000 hr [1,12, 13,15]. V. Foldnya, T. Prnka and M. Kadulova [12] have undertaken a preliminary comparison of the results of creep tests from the various testing programs. The creep tests of joint studies in the GDR have achieved testing times of more than 80,000 hr. In the present report, the most recent findings are presented, and are compared with earlier data [10,14,15] and with the results of the joint studies of other countries [1,12,13].

2. Test Melts and Heat Treatment

The tests are performed with 7 production-line melts. The chemical composition corresponds to the specifications for this steel as given in Table E 240-1. The individual chemical composition values were already reported earlier [10]. Five of these melts are tested in various heat-treated conditions, and are identified by the small letter following the melt number (Table E 241-1). Heat treatment data and the corresponding strength values obtained at 20° C are given in Tab. E 241-1.

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* Numbers in the margin indicate pagination in the foreign text.

3. Test Results

3.1. Time Yield Limit and Creep Strength Values

As of 3/30/71, the longest testing times are from 75,000 to 80,000 hr. Table E 242-1 contains the values derived for the time yield limit and creep strength. The scatter ranges of testing times for rupture and 1% elongation with mean-value curves are shown in Fig. E 243-1 and E 244-1. The data points provided with arrows in Figures E 243-1 and 244-1 designate the loads of the as yet unruptured specimens (Fig. E 243-1) or specimens in which 1% permanent elongation was not yet attained (Fig. E 244-1). The data points outside the scatter ranges for 500 and 550° C represent melt 522 with the highest strength of 98.7 kp/mm^2 at 20° C (Fig. E 243-1 and E 244-1).

According to the data in Table 242-1 and Figures E 243-1 and 244-1, the following mean values are derived for the 1% time yield limit and the creep strength for 100,000 hr at

500° C : 19.1 and 25.6 kp/mm^2
550° C : 10.7 and 13.5 kp/mm^2
600° C : 4.7 and 5.6 kp/mm^2

3.2. Creep-Rupture Elongation

The creep-rupture elongation values determined from previously ruptured specimens are indicated in Fig. E 251-1. The following can be concluded from this Figure:

-- The rupture elongations previously obtained are almost all greater than 10% up to the longest rupture times. The highest values are obtained at 500° C.
-- The values generally decrease with increasing testing time, some melts exhibiting a constancy or renewed increase in creep- /21
rupture elongation.
-- Melt 522 with the highest tempering strength exhibits the

lowest creep-rupture elongation values for all temperatures.

3.3. Tempering Strength and Creep Behavior

The tempering strength of the investigated melts at 20° C ranges from 76.6 to 98.7 kp/mm^2 (Table E 241-1). In consideration of the findings of R. Schinn [1], P. Mumme and G. Belka [10], as well as U. Schieferstein [13], a recent attempt was made (3/30/75) to determine the influence of tempering strength on creep behavior during long-term stressing. The results are given in Figures E 246-1, E 248-1 and E 250-1, and permit the following conclusions to be drawn:

- At 500° C the time-rupture curves are ordered according to tempering strength over all testing times (Fig. E 246-1).
- In contrast to the time-rupture curves at 500° C, those at 550° C are ordered according to tempering strength only up to a certain testing time (Fig. E 248-1). At testing times above approximately 50,000 hr, the time-rupture curves cross, and the behavior of tempering strength and creep strength becomes opposite.
- At 600° C, the shape of the time-rupture curves is like that at 550° C, except that the curves cross at shorter testing times (Fig. E 250-1).

3.4. Comparison of the Results of Joint Studies of Various Countries

The results of creep tests from the following testing programs are now available concerning the heat-resistant steel X22CrMoV 12.1:

- Joint experiments of the CSSR [12],
- the BBC (Escher-Wyss) Sulzer joint Swiss experiments [12],
- experiments of the joint study "Long-Term Creep Tests" and of additional testing laboratories of manufacturers and consumers of the FRG (summary evaluation) [13], /22

-- and experiments of the supraorganizational "Testing of Heat-Resistant Material" study group of the GDR [14].

The ranges of the chemical composition of all melts studied in the four testing programs are given in Table E 240-1. The creep specimens were taken in all four testing programs from starting material of various dimensions and with varying tempering strengths. The melts were combined into groups in the strength range 65--115 kp/mm^2 for evaluation. In the Czechoslovakian and Swiss testing programs, the statistical method was employed for evaluation and extrapolation; in the two German programs, graphic extrapolation.

Table E 245-1 shows a comparison of the mean and minimum values for 100,000-hr creep strength and permits the following conclusions:

-- At 500° C, tempering strength clearly influences creep behavior, as has been described by R. Schinn [1] and P. Mumme and G. Belka [10]. As strength increases in the interval 65--100 kp/mm^2, the mean and minimum values of creep strength also increase.
-- The mean values of the strength groups in the interval 65--100 kp/mm^2 range from 13.0 to 15.0 kp/mm^2 at 550° C. Only the mean value at 550° of the strength group 95--115 kp/mm^2 of the Swiss tests is significantly higher (17.0 kp/mm^2). It should be noted, however, that the strength interval is rather high, the test steels are alloyed with niobium, and the 100,000-hr values were mathematically extrapolated. The minimum values are in good agreement for the testing programs of the CSSR, FRG and GDR.
-- The mean and minimum values for 600° C of all four testing programs lie within a narrow scatter range, those of the CSSR, FRG and GDR showing good agreement.

4. Discussion

4.1. Creep Behavior

A comparison of the 1%/100,000-hr time yield limits and the 100,000-hr creep strength of the melts in Tab. E 242-1 with the corresponding values from the 1963 evaluation [10,15] with a maximum of 20,000 testing hours leads to the following determinations:

- At 500° C the new values of the 1% time yield limit are up to +2.6 kp/mm^2 higher than the old values; the creep strength values, up to +2.8 kp/mm^2 higher.
- For 550° C the deviations of the new values range from -1.0 to +0.9 kp/mm^2 for the 1% time yield limit and from -4.0 to 1.0 kp/mm^2 for creep strength. The 100,000-hr creep strength values from the 1963 evaluation were too high in the case of most melts.
- At 600° C the deviations range from -0.5 to 1.1 kp/mm^2 for the 1% time yield limits and -0.5 to 0.9 kp/mm^2 for creep strength.
- The comparison of the old and new mean values is as follows:

Year of evaluation	$\sigma_{1\%/100,000\ hr}$ in kp/mm^2 for 500°C	550°C	600°C	$\sigma_{B/100,000\ hr}$ in kp/mm^2 for 500°C	550°C	600°C
1963	16.9	11.3	4.5	23.3	15.6	5.8
1971	19.1	10.7	4.7	25.6	13.5	5.6

As the comparison shows, corrections are required in creep data, particularly at 500 and 550° C.

- A comparison of the creep data in Tab. E 242-1 with data from the evaluation of 3/30/68 (maximum 55,000 testing hours) reveals no significant deviations [14].

4.2. Creep-Rupture Elongation /24

As Fig. E 251-1 shows, for all melts except 694 c and 522, the values for creep-rupture elongation are greater than 10% at all temperatures. The ruptured creep specimens exhibit deformation-rich fractures in almost every case. The stronger decrease in creep-rupture elongation of melt 522 is apparently attributable to the high tempering strength. Despite this fact, the creep-rupture elongation values obtained for melt 522 are regarded as adequate. The low tendency of steel X22CrMoV 12.1 to become brittle is further characterized by the elastic reserve, i.e. the distance from the 1% time yield limit curve to the time-rupture curve. For 100,000 testing hours, the mean elastic reserve is

$6.5\ kp/mm^2$ at 500° C,
$2.8\ kp/mm^2$ at 550° C and
$0.9\ kp/mm^2$ at 600° C,

and indicates tha presence of an adequate elastic reserve up to the onset of fracture due to the low tendency to become brittle.

4.3. Tempering Strength and Creep Behavior

At 500° C, tempering strength (up to 100 kp/mm^2) clearly influences creep behavior up to testing times of 100,000 hr, as has been described by R. Schinn [1]. Due to the low tendency of steel X22CrMoV 12.1 to become brittle, practical use can be made of this effect.

At temperatures higher than 500° C, tempering strength values greater than 95 kp/mm^2 have no positive effect on creep behavior during long-term stressing. It is found that melts in the lower region of the tempering range from 80 to 95 kp/mm^2 exhibit a smaller slope of the time-rupture curve and creep strength values for 100,000 hr equal to or slightly greater than those of melts in the upper region of the tempering range or above it.

4.4. Evaluation of the Joint Studies of Various Countries /25

A comparison of the results of evaluations of data obtained by the four testing programs of various countries shows that -- excluding the results for 500° C -- the results are in good agreement despite differences in evaluation methods and testing conditions. The considerable scatter of test results at 500° C can be attributed to several factors, including differences in tempering strength at 20° C despite classification of the melts according to strength. The location of the statistical distribution of strength in the prescribed tempering range (e.g. 65-80 or 80-95 kp/mm^2) has a considerable effect on creep behavior at 500° C. It should also be noted that the values of the Swiss experiments for 500° C were extrapolated from the tests at 550 and 600° C by the Larson-Miller method.

5. Summary

By continuing the creep tests begun in 1961 and evaluated in 1963 and 1968, the values obtained by these intermediate evaluations could be largely confirmed. Comparison of our test results with those of other countries shows good agreement with respect to creep data. In view of the good agreement of creep data based on long-term tests conducted in various countries and in consideration of the specimens still intact, no significant changes in the 100,000-hr data are anticipated on continuance of the tests. Nevertheless, the tests will be continued on the still-unruptured specimens in the hope of one day providing reliable 200,000-hr creep data.

TABLES AND FIGURES

TABLE E 240-1: CHEMICAL COMPOSITION OF HEAT-RESISTANT 12% CHROMIUM STEELS OF VARIOUS COUNTRIES OF ORIGIN

	a) Land	b) Bezeichnung Stahltyp	c) Chemische Zusammensetzung in % C	Si	Mn	Cr	Ni	Mo	W	V	Nb
d	Schweiz	Cr-Mo-V-Nb	0.16 0.26	—	—	10.30 13.20	0.20 1.20	0.50 1.50	0 0.80	0.20 0.70	0 0.70
e	ČSSR	ČSN 17134	0.17 0.23	0.25 0.60	0.50 1.00	10.60 12.00	0.30 0.80	0.80 1.20	0.40 0.80	0.20 0.35	—
f	BRD	X 22 CrMo(W)V 12.1	0.18 0.25	0.10 0.50	0.30 0.80	11.00 12.50	0.30 0.80	0.80 1.20	(0.50)	0.25 0.35	—
g	DDR	X 22 CrMoV 12 1	0.18 0.25	0.30 0.50	0.20 0.40	11.50 12.50	—	0.90 1.10	—	0.25 0.35	—

Key:
a) Country
b) Designation, steel type
c) Chemical composition in %
d) Switzerland
e) Czechoslovakia
f) FRG
g) GDR

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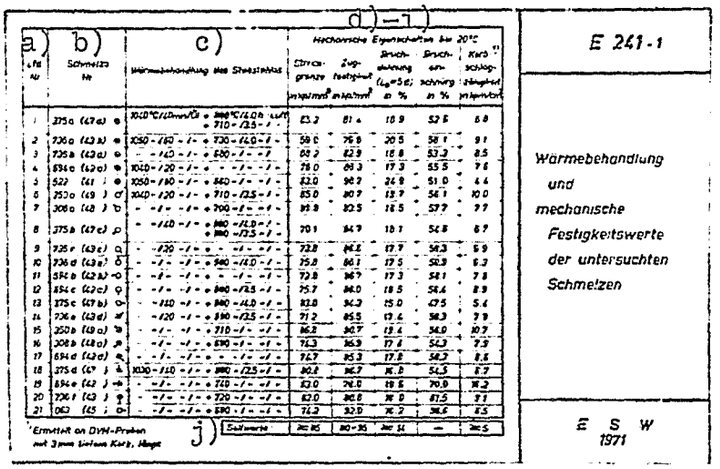
TABLE E 241-1: HEAT TREATMENT AND MECHANICAL STRENGTH VALUES OF THE INVESTIGATED MELTS



a) Lfd. Nr.	b) Schmelz Nr.	c) Wärmebehandlung des Stahlstabs	d)–i) Mechanische Eigenschaften bei 20°C: Streck-grenze in kp/mm²	Zug-festigkeit in kp/mm²	Bruch-dehnung (l_0=5d) in %	Bruch-einschnürung in %	Kerb-schlag-zähigkeit in kpm/cm²
1	375a (47a) e	1010°C/Luft + 860°C/4,0h Luft + 710 – /3,5 – / –	63,2	81,4	18,9	52,5	6,8
2	726a (42a) e	1050 – /10 – / – + 720 – /4,0 – / –	59,6	76,8	20,5	56,1	9,1
3	726a (42a) e	– – /10 – / – + 690 – / – – / –	60,2	82,9	18,8	53,2	8,5
4	694a (42a) e	1040 – /20 – / – + – – / – – / –	78,0	88,3	17,3	55,5	7,6
5	522 (41) e	1050 – /10 – / – + 840 – / – – / –	63,0	96,2	24,9	51,0	4,4
6	750a (49) d	1040 – /20 – / – + 710 – /2,5 – / –	65,0	80,7	13,7	56,1	10,0
7	306a (42) b	– – / – – / – + 700 – / – – / –	59,8	82,5	18,5	57,7	7,7
8	375a (47c) p	– – /10 – / – + 860 – /4,0 – / – + 680 – /2,5 – / –	70,1	84,9	18,1	54,8	6,7
9	725r (43e) q	– – /20 – / – + – – / – – / –	72,8	86,6	17,7	56,3	5,9
10	726d (43a) r	– – / – – / – + 840 – /4,0 – / –	75,8	86,1	17,5	50,9	6,3
11	594b (42b) s	– – / – – / – + – – / – – / –	72,8	86,7	17,3	54,1	7,8
12	854c (42c) q	– – / – – / – + 840 – /2,5 – / –	75,7	86,0	18,5	54,4	8,9
13	375c (47b) t	– – /10 – / – + 840 – /4,0 – / –	63,8	84,3	15,0	47,5	5,4
14	726a (43d) u	– – /20 – / – + 690 – /2,5 – / –	71,2	85,5	17,6	58,3	7,9
15	250b (49a) v	– – / – – / – + 710 – / – – / –	66,2	80,7	13,4	54,0	10,7
16	308b (48a) w	– – / – – / – + 690 – / – – / –	74,3	86,9	17,4	54,3	7,9
17	694d (42d) x	– – / – – / – + – – / – – / –	74,7	85,3	17,8	54,7	8,6
18	375d (47) y	1030 – /10 – / – + 880 – /2,5 – / –	60,2	86,7	16,8	54,5	8,7
19	694e (42) z	– – / – – / – + 710 – / – – / –	62,0	76,0	19,6	70,9	14,2
20	726f (43) ä	– – / – – / – + 720 – / – – / –	62,0	80,8	16,9	61,5	9,1
21	060 (45) ö	– – / – – / – + 690 – / – – / –	74,2	92,0	16,2	58,6	8,5
'Ermittelt an DVM-Proben mit 3 mm tiefem Kerb, Hagé		j) Zahlwerte	≥ 60	80–95	≥ 14	–	≥ 6,5

E 241-1

Wärmebehandlung und mechanische Festigkeitswerte der untersuchten Schmelzen

E S W 1971

Key:

a) Serial no.
b) Melt no.
c) Heat treatment of steel bar
d) Mechanical properties at 20° C
e) yield point in kp/mm^2
f) tensile strength in kp/mm^2
g) rupture elongation in %
h) rupture constriction in %
i) notch-impact strength[1] in kpm/cm^2
j) theoretical values

1. Determined on DVM specimens with longitudinal notch 3 mm in depth.

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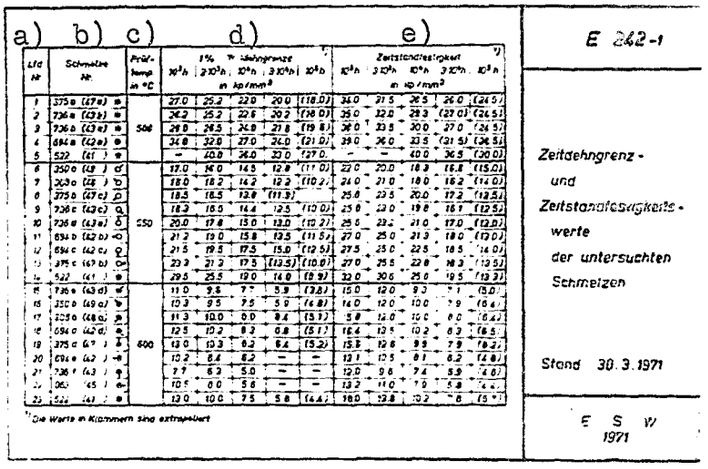
TABLE E 242-1: TIME YIELD LIMIT AND CREEP STRENGTH VALUES OF THE INVESTIGATED MELTS (3/30/71)



a) b) c) d) e)

E 242-1

Lfd. Nr.	Schmelze Nr.	Prüftemp. in °C	1% Zeitdehngrenze in kp/mm² 10⁴h	3·10⁴h	10⁵h	3·10⁵h	10⁶h	Zeitstandfestigkeit 1) in kp/mm² 10⁴h	3·10⁴h	10⁵h	3·10⁵h	10⁶h
1	375 a (47a)	500	27.0	25.2	22.0	20.0	(18.0)	34.0	31.5	26.5	26.0	(24.5)
2	736 a (43a)		24.2	25.2	22.6	20.2	(18.0)	35.0	32.0	28.2	(27.0)	(26.5)
3	736 b (43c)		28.8	24.5	24.8	21.8	(19.8)	36.0	33.5	30.0	27.0	(26.5)
4	684 a (42a)		34.8	32.0	27.0	24.0	(21.0)	39.0	36.0	33.5	(31.5)	(26.5)
5	522 (41)		–	40.0	36.0	33.0	(27.0	–	–	40.0	36.5	(30.0)
6	350 c (48)	550	17.0	14.0	14.5	12.8	(11.0)	22.0	20.0	18.8	16.8	(15.0)
7	350 c (48)		18.0	18.2	14.2	12.2	(10.2)	24.0	21.0	18.0	16.2	(14.0)
8	375 b (47c)		18.5	16.5	12.8	(11.3)		25.8	23.5	20.0	17.2	(13.5)
9	736 c (43c)		18.3	16.0	14.4	12.5	(10.0)	25.8	23.0	19.8	16.1	(12.5)
10	736 a (43a)		20.0	17.8	15.0	13.0	(10.2)	25.5	23.2	21.0	17.0	(12.0)
11	684 b (42b)		21.2	19.0	15.8	13.5	(11.5)	27.0	25.0	21.3	18.0	(13.0)
12	684 c (42c)		21.5	19.5	17.5	15.0	(12.5)	27.5	25.0	22.5	18.5	(14.0)
13	375 c (47b)		23.2	21.2	17.5	(13.5)	(10.0)	27.0	25.5	22.8	18.3	(13.5)
14	522 (41)		29.5	25.5	19.0	16.0	(9.9)	32.0	30.6	25.0	19.5	(13.3)
15	736 a (43d)	600	11.0	9.5	7.7	5.9	(3.8)	15.0	12.0	8.3	7.1	(5.0)
16	350 b (48a)		10.3	9.5	7.5	5.9	(4.8)	14.0	12.0	10.0	7.9	(6.4)
17	350 b (48a)		11.3	10.0	8.0	6.4	(5.1)	15.8	14.0	11.0	8.0	(6.4)
18	684 a (42a)		12.5	10.2	8.2	6.8	(5.1)	16.4	13.5	10.2	8.2	(6.5)
19	375 a (47a)		13.0	10.3	8.2	6.4	(5.2)	15.8	12.8	9.9	7.8	(6.2)
20	684 a (42a)		10.2	8.4	6.2	–	–	13.1	10.5	8.1	6.2	(4.8)
21	736 a (43a)		7.7	6.3	5.0	–	–	12.0	9.6	7.4	5.9	(4.8)
22	350 c (48)		10.5	8.0	5.6	–	–	13.2	11.0	7.9	5.8	(4.4)
23	522 (41)		13.0	10.0	7.5	5.8	(4.4)	16.0	13.8	10.2	8	(5.9)

1) Die Werte in Klammern sind extrapoliert

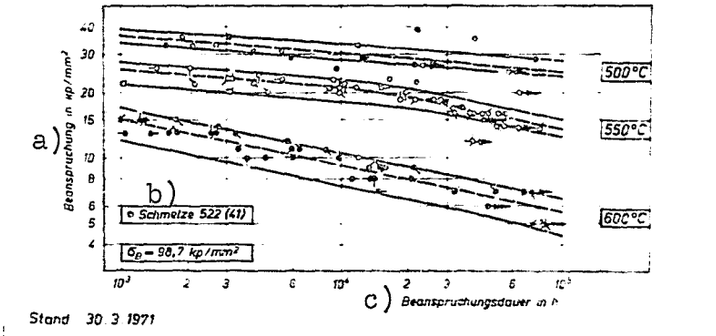
Zeitdehngrenz- und Zeitstandfestigkeitswerte der untersuchten Schmelzen

Stand 30.3.1971

E S W 1971

Key: a) Serial no.
b) Melt no.
c) Testing temp. in °C
d) 1% time yield limit
e) creep strength

1) The values in parentheses are extrapolated



Stand 30.3.1971

E S W 1971	Streubereiche der Versuchszeiten für Bruch bei 500, 550 und 600°C der Schmelzen nach Tabelle 2	E 243-1

Fig. E 243-1: Scatter of testing times for rupture at 500, 550 and 600° C of the melts according to Table 2 (3/30/71).

Key: a) Stress in kp/mm^2
b) melt 522
c) Stressing time in hr

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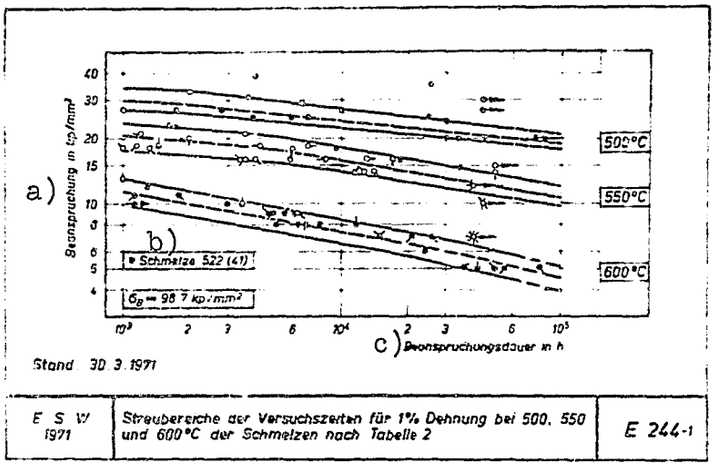

Fig. E 244-1: Scatter of testing times for 1% elongation at 500, 550 and 600° C of the melts according to Table 2 (3/30/71).

Key:

a) Stress in kp/mm^2
b) melt 522
c) Stressing time in hr

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TABLE E 245-1: COMPARISON OF MEAN AND MINIMUM VALUES OF CREEP STRENGTH $\sigma_{B/100,000\ hr}$ (RESULTS OF EVALUATIONS OF JOINT STUDIES IN VARIOUS COUNTRIES

a) Land	b) Bezeichnung Stahltyp	c) Zugfestigkeitsbereich bei 20°C in kp/mm²	d)–f) Zeitstandfestigkeit $\sigma_{B/100\,000}$ in kp/mm² Mittelwerte für 500°C	550°C	600°C	Mindestwerte für 500°C	550°C	600°C
g) Schweiz [3]	Cr-Mo-V-Nb h)	65 bis 80	22.5 1)	13	5	17 1)	9	3
		80 bis 95	26 1)	14	5	19 1)	10	3
		95 bis 115	—	17	5	—	12	3
i) ČSSR [3]	ČSN 17134	73 bis 83	—	13.2	5.8	—	10.8	4.8
j) BRD [4]	X 22 CrMo(V)V 12 1	65 bis 80	23	13	5	24.5	11.5	4.5
		80 bis 95	30	15	5.6	27	13	4.5
k) DDR	X 22 CrMoV 12.1	76.6 bis 88.3	25.6	—	—	24.5	—	—
		98.7	30	—	—	30	—	—
		76.6 bis 98.7	—	13.5	5.6	—	12.5	4.4

1) Extrapoliert aus Versuchen bei 550 und 600°C nach der Methode von Larson-Miller

l) Versuchsstand Schweiz Anfang 1963 BRD Anfang 1967 ČSSR Anfang 1967 DDR 30.3.1971

E S W 1971 | Vergleich der Mittel- und Mindestwerte der Zeitstandfestigkeit $\sigma_{B/100\,000}$ Auswertungsergebnisse d. Gemeinschaftsuntersuchungen versch. Länder | E 245-1

Key:

a) Country
b) Designation, steel type
c) Tensile strength range at 20° C in kp/mm²
d) Creep strength σ_{B} 100,000 hr in kp/mm²
e) Mean values for
f) Minimum values for
g) Switzerland
h) 65 through 80, 80 through 95, etc.
i) Czechoslovakia
j) FRG
k) GDR
l) Swiss tests: early 1963, Czechoslovakia: early 1967, FRG: early 1967 GDR: 3/30/71

1) Extrapolated from tests at 550 and 600° C by the Larson-Miller method.

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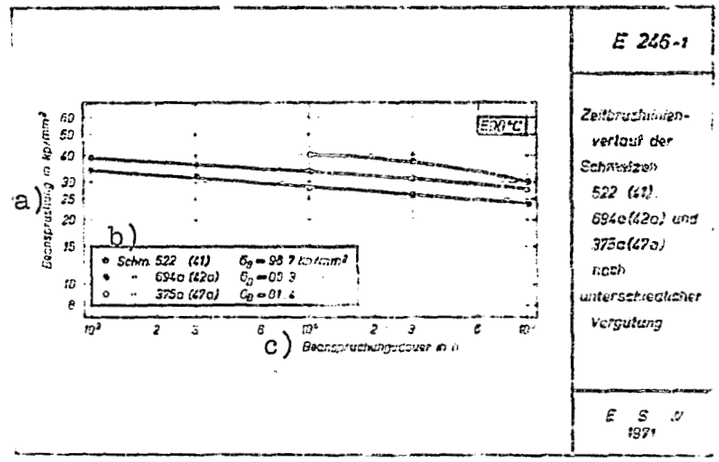

Fig. E 246-1: Time-rupture curves of melts 522 (41), 694a (42a) and 375a (47a) after different heat treatments.

Key: a) Stress in kp/mm^2
b) melt 522, etc.
c) Stressing time in hours

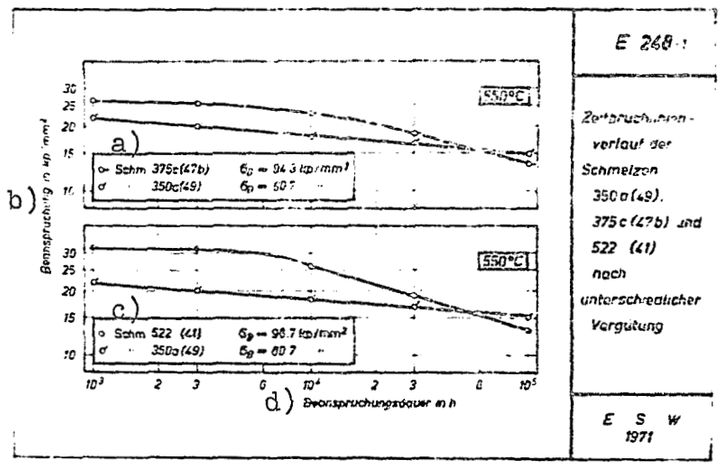

Fig. E 248-1: Time-rupture curves of melts 350a (49), 375c (47b) and 522 (41) after different heat treatments.

Key: a) melt 375c, etc.
b) Stress in kp/mm^2
c) melt 522, etc.
d) Stressing time in hr

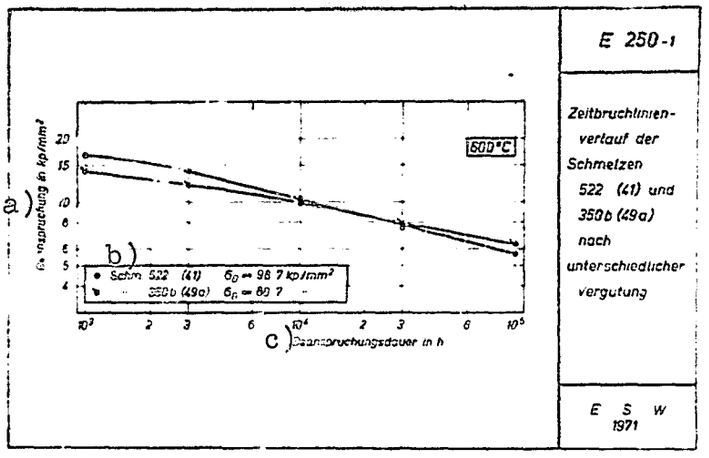

Fig. E 250-1: Time-rupture curves of melts 522 (41) and 350b (49a) after different heat treatments.

Key: a) Stress in kp/mm^2
b) melt 522, etc.
c) Stressing time in hr

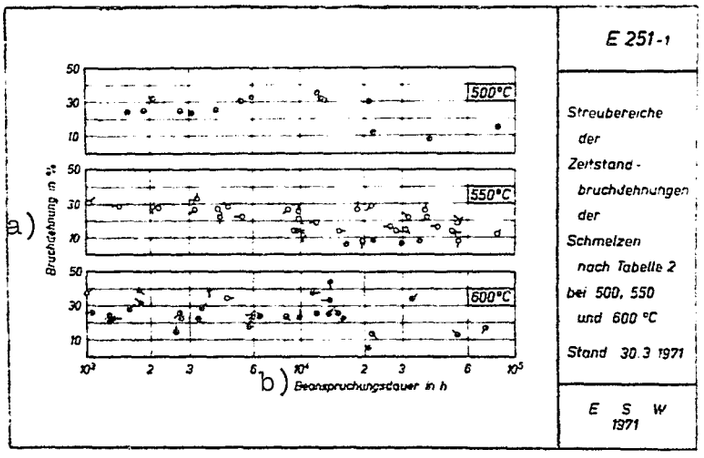

Fig. E 251-1: Scatter of creep-rupture elongations of melts according to Tab. 2 at 500, 550 and 600° C (3/30/71).

Key: a) Rupture elongation in %
b) Stressing time in hr